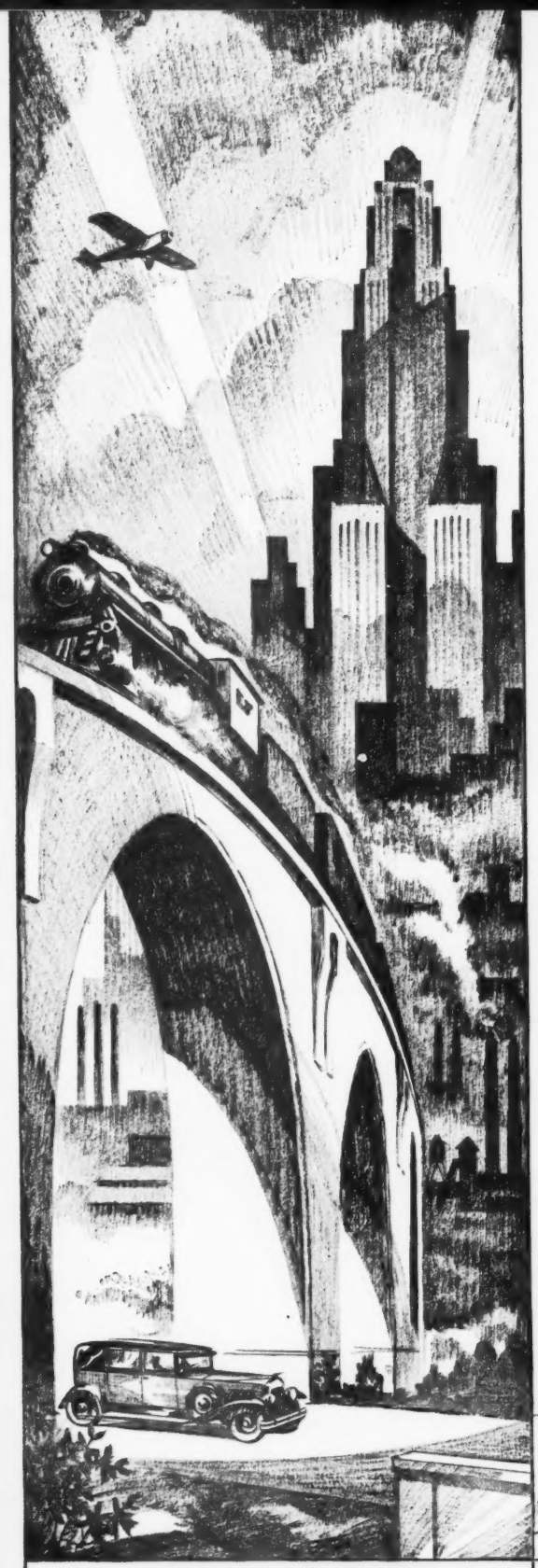

The CRUSHED STONE JOURNAL

PUBLISHED QUARTERLY

In This Issue

Observations on the "Pumpcrete" Method of Conveying Concrete

Design and Construction of Flight Strips

Tests on a Special Type of Double Surface Treatment

Gone With the Winter

Coal Dust

The Post-War Highway Program

March · 1943

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The Bulking of Sand and Its Effect on Concrete

BULLETIN No. 2

Low Cost Improvement of Earth Roads with Crushed Stone

BULLETIN No. 3

The Water-Ratio Specification for Concrete and Its Limitations

BULLETIN No. 4

"Retreading" Our Highways

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Reprint of "Comparative Tests of Crushed Stone and Gravel Concrete in New Jersey" with Discussion

BULLETIN No. 6

The Bituminous Macadam Pavement

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The Crushed Stone Journal

Official Publication of the NATIONAL CRUSHED STONE ASSOCIATION

J. R. BOYD, Editor

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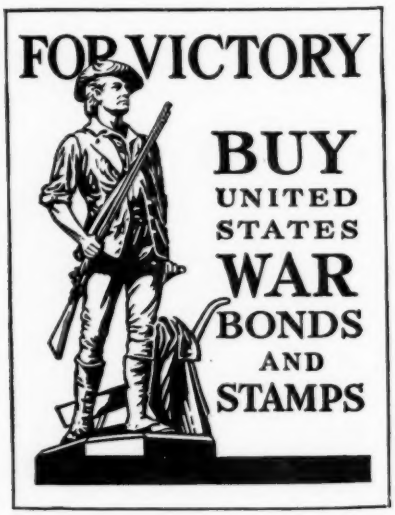

THE CRUSHED STONE JOURNAL

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Observations on the "Pumpcrete" Method of Conveying Concrete

By R. T. SHERROD[1]

• **When concrete is placed by the method of pumping, workability is of especial importance. Of particular interest to stone producers is the successful pumping of crushed stone concrete far beyond recommended distances, an indication of excellent workability.**

Growth of Pipeline Concreting System

IN THE eleven year period since its American inception late in 1932, the concrete pump, (the Rex Pumpcrete), has passed through what might be termed the swaddling and toddling stages of its development. Several millions of cubic yards of concrete are now being pumped annually. Its usage has spread of recent years until pipeline concrete is now adapted to virtually every branch of structural concrete construction, excepting only road paving, such structures as can be poured by gravity from truck mixers or pavers and the large, mass-concrete projects where over-size aggregates rule it out. Even road slabs and other structures that would ordinarily be poured directly from the mixer are pumped occasionally where abnormal subsoil conditions or obstacles of one kind or another make them difficult of access to rolling equipment.

The economic advantages of a system that will transport (on one or more levels), elevate, or lower and distribute concrete in one operation, thereby eliminating rehandling, are quite obvious on innumerable projects involving many types of construction. Always provided, of course, that it works; that the system is practical.

More than a degree of economic practicality is attested for the Pumpcrete in that its place in the field of concrete placing equipment is expanding steadily. However, in common with most machines and most systems in general, especially those encompassing a wide scope of endeavor, its practicality and usefulness is largely in ratio to the understanding with which it is applied as a machine and as a concreting system.

If Analogy Be In Order:

The power shovel slugging it out in sandy loam today will sing a different tune when it hits shale or hard pan tomorrow. And so on, *ad infinitum*, with earth-moving and drilling equipment, dredges, etc., (not mentioning crushing plants), right on down the line with everything that moves or is moved.

The trucking contractor does not expect the same unit performance in the oil fields or in an outlying swamp that he realizes on city streets and he organizes his job accordingly. The same variations of operational efficiency with the Pumpcrete should not occasion surprise to anyone familiar with any type of construction equipment.

It is only natural that the organizations with a varied background of pumping experience do things as a matter of course that will often completely stump the tyro. In spite of its wide usage, pipeline concrete remains somewhat of a mystery to many individuals and firms, even in those localities where its use is most common, and not excepting some organizations who have tried it out haphazardly. Some of the basic principles which make it tick and which govern how well it ticks are covered in the following remarks.

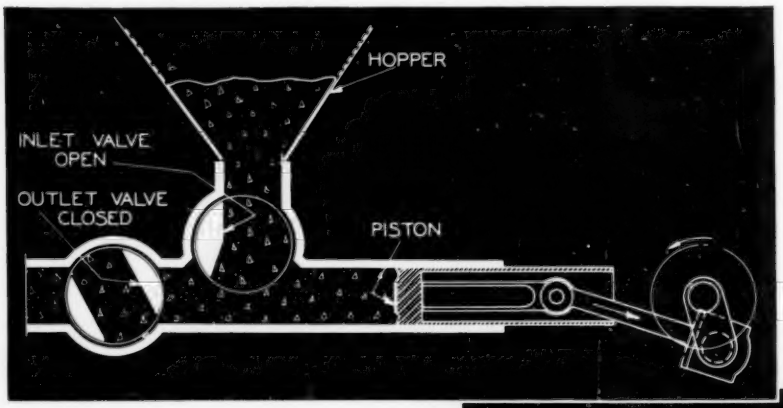
[1] Manager Pumpcrete Department; Construction Machinery Division Chain Belt Company, Milwaukee, Wis.

Description of the Pumpcrete

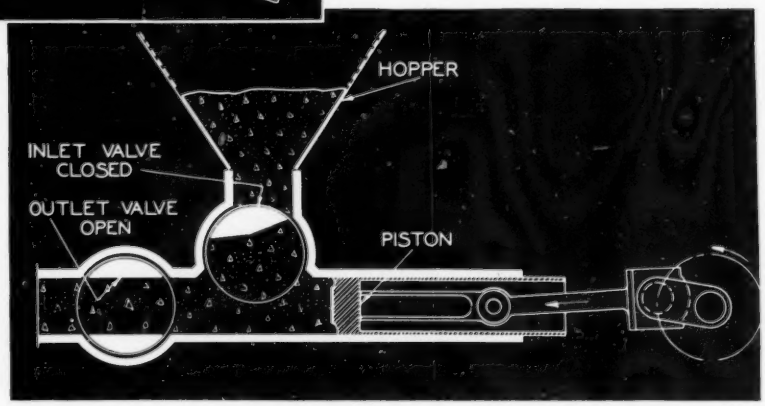
For the benefit of those to whom it is still an unknown quantity, the Pumpcrete is described as a heavy-duty, single-action piston pump of conventional crankshaft and connecting rod design. The bore diameter is 160 millimeters (6.3 in.) in the smallest size and 200 millimeters (7.9 in.) in the largest size pump and piston has a 12 in. stroke and operates at 50 strokes per minutes. As illustrated in the accompanying figure, the intake and discharge valves are modified plug cocks, mechanically operated. The cylinder is disposed horizontally with the discharge valve and pipeline connection directly in line with the piston's travel. The intake valve is located beneath a supply hopper which in all modern machines is equipped for remixing the concrete.

Both intake and discharge valves and the outlet passage into the pipeline are the same size as the piston, and the pipeline must be very nearly as large because of certain innate characteristics of concrete, which at best is only a semi-fluid and stubbornly resists appreciable constriction.

The valves are actuated in timed relationship to the movement of the piston and are designed to take advantage of the stowing action of concrete and do not make full closure except when pumping grout. Valve closure is set to about the same size as the largest aggregate in the mix by means of simple adjustments on the valve lever arm.



Inlet valve between hopper and chamber is opened to allow charge of concrete to be drawn into the cylinder by suction of the piston. At this time, the outlet valve is closed.



Outlet valve is opened, and with inlet valve closed, piston forces charge of concrete through outlet passage. Valves, which are called "plug cocks," are opened and closed in timed relationship to the movements of the piston.

The parts of the Pumpcrete coming into contact with concrete are replaceable. Valve chambers, passages and cylinder are equipped with abrasion resistant liners. The piston has a replaceable rubber head and operates in a sealed jacket, from which a flushing system removes any grout that might escape past the head as it becomes worn.

The Pipeline

The concrete is pumped to the point of deposit through lightweight steel tubing 6, 7 or 8 in. outside diameter, provided in various lengths and with the necessary fittings and connections suitable for the particular job. Much could be written about the design of the pipe line which however must be omitted.

Elbows have a sixty-two inch radius and it is preferable to have the pipe diameter approximate that of the piston so as not to constrict the concrete. The pipeline cannot be reduced to a smaller size pipe or hoses at point of distribution, nor can the stream of concrete be divided into branches. Two streams however maybe made to merge into one larger stream.

Method of Cleaning Pipeline

Upon completion of a pour, the pipe is cleaned by means of a dumb-bell shaped device with cupped rubber flanges called a go-devil. The procedure runs as follows: When all of the concrete is pumped into the pipe the line is disconnected at the pump; the hopper and valves are hosed clean and the Pumpcrete converted to a water pump by insertion of a check valve in a slot provided for the purpose just above the intake valve-plug. Another check valve is fitted in a hose connection from the pump to the pipe to take care of back pressure. A pair of go-devils are inserted in the pipe and pumped through the line by water pressure. The location of the go-devil can be followed at all times and except on down grade runs, it can be stopped at any point in the line by stopping the pump. Single pumps are converted for the washout in about 5 minutes, doubles in 10 minutes. On jobs where it is difficult to dispose of the washout water, the pipe is cleaned in very much the same manner by means of compressed air, but a tightly rolled and saturated burlap plug is usually substituted for the go-devils.

The Pumpability of Concrete Defined

As a substance concrete can be postulated just about as reliably as human nature. Individual mixtures are sometimes subject to rather peculiar whimsies but in the main concrete can be pumped easily enough within the prescribed limitations.

Concrete in the freshly mixed state is pumpable because of its relative non-compressibility and properties of self-lubrication. In addition to these properties, it must be fluid enough to lie against the sides of the charging hopper (sealing air from the pump-chamber) and to flow through the intake mechanism and it must be stiff enough to hold together in a homogeneous mass without appreciable separation of the aggregate particles in order that it may be pumped satisfactorily.

When a specific concrete is said to be a good, pumpable mix, it means it can easily be pumped the distance and at the hourly capacity shown in Table I. The majority of every day concrete mixtures made from well graded natural aggregates and falling within a 2 to 6 inch slump range will exceed the distance rating somewhat.

Some few materials here and there are recognized as hopeless, but most borderline concretes are easily corrected for sufficient pumpability to suit average conditions.

The more plastic mixtures can be and very frequently are pumped 50 per cent farther than the recommended distance. This is about the limit for sound practice even with the most pumpable mixes; but concrete has been successfully pumped over 2,000 lineal feet horizontally. A 185 ft. lift plus a 200 ft. horizontal run is the record for vertical pumping.

The foregoing records were made possible by a combination of favorable circumstances not to mention operational knowledge. Anyone who feels called upon to try bettering the record has our apprehensive sympathy. He does not have our approbation. The Pumpcrete is not mechanically designed to work against such loads.

Most of the factors that make for workability, plasticity, cohesiveness, mobility, etc., also promote pumpability, but the latter expression has a dual meaning. One phase of pumpability has to do with the speed or hourly rate at which a concrete can be pumped, the other deals with the distance it can be pumped.

The Pumpcrete as illustrated in Figure 1, operates by displacement. Given proper adjustment of the machine and normal concrete, what drops into the pump chamber must go into the pipeline, as long as the pump is running. There are minor exceptions to this statement under some conditions, but they do not affect the principle and will be ignored in this comparison.

It will be seen that the discharge valve is closed as the intake valve between the hopper and pump chamber opens and concrete is drawn into the cylinder by gravity and the suction of the piston. As the piston starts forward on the power stroke, the intake valve closes, the discharge valve opens, and the charge of concrete is pushed into the pipeline. In other words, the hourly rate at which any individual concrete can be pumped is in direct ratio to its flowability or mobility. It must be mobile enough to charge the pump.

The distance that any concrete can be pumpd successfully is determined by its quality of resistance to pumping pressure or non-compressibility, which in

turn is regulated by its cohesiveness (or freedom from segregation), qualities of lubrication (a combination of the type, grading, and quantity of both the sand and cement) and the overall density of the mix.

Cement and Sand Requirements For Pumpable Concrete

There have been a few occasions on which concrete with 4 bags of cement per cu. yd. and 1½" or 2" maximum size aggregate has been pumped successfully. This has only been possible where the grading, type and control of aggregates was unusually favorable and where pumping ranges were moderate. By way of comment, such accomplishments sometimes are bruited about without explanation of the extenuating circumstances. What's good for Peter isn't always good for Paul.

With most materials, about 4½ bags per cu. yd. is the absolute minimum cement requirement for pumpable concrete. Five bags per cu. yd. should be the minimum requirement for aggregates of a relatively high surface area and some few aggregates combined with a poorly proportioned sand will require as much as 5½ to 6 bags of cement to show good pumping results. It is our opinion that anything in excess of 6 bags of one type of cement per cu. yd. is just excess baggage insofar as the pumpability of concrete is concerned. Special concretes with up to 12 bags of cement have been pumped but they have never to our knowledge exhibited pumping qualities superior to those of a good plastic 5 bag mix. However, the addition of another type of cement as a blend will often increase the distance a badly bleeding mix can be pumped. Sometimes a blend of very fine sand will do the same thing.

The percentage of sand required for pumpability is of course another variable, depending entirely on overall grading, surface area, and cement content.

Any structural concrete that is designed for sufcient workability to meet average placing requirements must have enough mortar to properly separate the coarse aggregate so that the individual pieces can move freely with respect to one another without jamming together. This rule governing the workability of concrete applies to its pumpability. Naturally the minimum percentage of sand which will accomplish this purpose is desirable, but the surface area and void ratio or grading of the coarse aggregate tells the story. Aggregates with a high percentage of voids will require a high percentage of sand for pumpability.

Effect of Slump on Pumpability

Concretes made from well graded and proportioned materials are frequently pumped at slumps as low as one inch.

However, dry concrete will not usually feed into the pump as readily as the more plastic mixes, consequently the hourly rate of production can be expected to fall off as the slump goes down. Dry concrete is not usually as plastic and does not trowel as easily as the more plastic mixes, therefore, pipe friction is increased and the maximum pumping range of a given concrete decreases as the slump goes down below that certain point.

The difference of 1 to 2 inches of slump in dry concrete, say the spread between 1 to 3 inches will often make a difference of 25% or more in both the rate of production and the distance that a given concrete can be pumped.

At the same time, attention is called to the fact that slump consistency is a poor yardstick by which to measure the mobility of concrete. An occasionally gummy or sticky mix will not feed properly at a 6 inch slump. Some concretes will begin to fall off in hourly production at a 3 to 4 inch slump; others will continue to give full production right down to minus 2 inch slumps, but the latter condition is seldom found with aggregates exceeding 1½ inch size.

Neither is slump an exact gauge of plasticity or density. Many well graded concretes that will not slump 2 inches can be pumped farther than some mixes that have a much higher cement factor and will slump 6 inches.

As a general purpose rule: A 3 to 4 inch slump is about the best for all-around conditions; the maximum distance can be reached with plastic concrete of 6 to 7 inch slump; concrete that bleeds copiously will give better pumping results if held on the dry side; and very wet concrete that is to be pumped a long distance must usually be oversanded and have plenty of cement if excessive segregation is to be avoided.

Common Causes of Pumping Difficulty

The following remarks are not intended to cover errors of mechanical omission and commission; such incidental accidents as leaving the sand or cement out of a mix or doubling up one of the aggregates or the water and then trying to force the mess through the pipeline. These and similar miscues are not unusual but can only come under the heading of bad judgment.

TABLE I

Capacities and Material Limitations of the Pumpcrete

Model Pumpcrete Size of Piston	Size of Pipeline	Maximum Recommended Pumping Distance—Equivalent length*	Maximum Recommended Pumping Height**	Maximum Size Aggregate All passing Sq. Op. Screen	Hourly Pumping Capacity
No. 200 Single (7.9" bore)	8" OD	1000′	120′	3"	25–33
	7" OD	600′	100′	2½"	
No. 200 Double (7.9" bore)	8" OD	1000′	120′	3"	50–65
	7" OD	600′	100′	2½"	
No. 160 Single (6.3" bore)	7" OD	1000′	100′	2"	15–20
	6" OD	800′	100′	2"	
No. 160 Double (6.3" bore)	7" OD	1000′	120′	2"	30–40
	6" OD	800′	100′	2"	

* A 90 degree elbow is figured as equivalent to 40 ft., a 45 degree equivalent to 20 ft. and a 22½ degree elbow equivalent to 10 ft. of straight horizontal piping.

** Not over 200 ft. of pipe actually. A combination of horizontal and vertical distances is calculated on the basis of one ft. of vertical pumping being equal to approximately 8 ft. of horizontal pumping. The total equivalent distance should not exceed the equivalent horizontal pumping distances shown in the tabulation unless the concrete is known to possess unusual characteristics of plasticity, density, etc.

It should be noted that except for the model 160 single which is sold with either 6" or 7" OD pipe the largest size pipe shown above is the only size now available with new machines.

Concrete mixtures that are difficult to pump include those which are too wet and not cohesive enough to hold together without serious particle separation; mixes that are too dry and will not feed into the pump chamber; those that are too harsh from being poorly graded or undersanded; those without enough cement; those with aggregates too large for the machine (See Table I); and mixes containing an excess of porous, highly absorptive aggregates.

Most of the foregoing conditions are not hard to straighten out, but porous aggregates should receive special mention. When concrete contains highly porous aggregate, not fully saturated before pumping, water may be forced into the pores by pumping pressure. This is called "forced absorption." In abnormally light aggregates where only a small percentage of the pores are saturated before or during mixing, such action is general.

Forced absorption may also cause trouble occasionally with aggregates of normal weight, but with appreciably high porosity. This is especially true with dry mixes. Suppose an aggregate has an absorption of 2% by weight and is only half saturated when it goes into the Pumpcrete. The 1% of remaining absorption amounts to around 2.7% by volume and this may amount to 10% of the mixing water by volume. If water is squeezed into the pores by pressure to the equivalent of 1% by weight of aggregate, then the action may amount to reducing initially the mixing water by nearly 10%. If an initially-dry mix were being used, such further drying while under pressure might make it impossible to pump without an increase of the mixing water. Whenever possible, it is a good idea to keep stock piles of porous, absorptive aggregates saturated before mixing.

It should go without saying that any aggregate that is so porous it will sop up an amount of water exceeding the specifications and limitations of sound practice, is not suitable material for pumping.

Crushed Aggregates with the Pumpcrete

It is generally believed crushed materials are harder to pump than gravel aggregates. In a limited sense, this is correct. However, in pumping several millions of cubic yards of crushed stone concrete, the point has been very definitely established that the difference in the pumpability of individual mixtures, whether made with gravel or crushed stone is primarily one of design and control.

Properly graded crushed stone concretes with aggregates up to 1½ inch maximum size, and possibly larger with the more cubical materials, will feed into the Pumpcrete just as readily as gravel concretes made of the same size aggregate and with slump consistency. With 2½ to 3 inch aggregates, especially when the crushed material has a high percentage of long splintered particles, gravel will usually show a

somewhat more favorable pumping rate. Given equal grading, equal absorption, enough good sand to compensate for the voids, the same cement and the same slump consistency, there should be small difference in the pumpability of stone as compared to gravel concrete.

Representative stone concretes that have been placed by the Pumpcrete are shown in Table II.

Remarks on Representative Crushed Stone Mixes[1]

1. This concrete was hauled a mile in flat-bottom dump trucks before going into the Pumpcrete. It pumped like butter, consistently hitting an hourly rate above the top rated capacity of the machine at ranges in excess of the recommended maximum pumping distance.

[1] NOTE: With the exception of #9 and #10, all of the foregoing concretes were pumped with the small size Pumpcretes, which handle a maximum size aggregate of 2". Jobs #9 and #10 were pumped with Model 200 doubles, which will handle aggregates up to 3" maximum size. All quantities and gradations were of course subject to the usual variations from the average.

2. Another good concrete from the standpoint of pumpability—On several occasions due to delays at the form it stood in the pipeline 45 minutes to one hour without movement and pumped right on out. It also exceeded the top rated capacity of the machine consistently with the slump range shown.

3. This concrete was never pumped farther than six or seven hundred feet, so its full qualifications as to pumpability could not be gauged. The maximum rated pumping capacity was maintained with a 3" slump, and it gave every indication of being willing to step out a much farther distance if it had been required.

4. The maximum production rate was maintained at all times, but the concrete would not withstand enough pumping pressure to go out beyond 700 ft. without running into pipeline trouble. The nature of the job, (a 1200 ft. underpass poured progressively, with Pumpcrete charged by Paver) was such that the contractor, although he had intended to pump the job from one end of the structure, elected to move

TABLE II

Representative Crushed Stone Concrete Mixtures Placed By Pumpcrete

	1	2	3	4	5
Stone, Type	Limestone	Limestone	Limestone	Limestone	Feldsparific Quartzite
Sand, Type	Washed River	Screened Bank	Screened Bank	Great Lakes	Screened Bank
Cement, Type	High Early Strength	Std. Port.	Std. Port.	Std. Port.	Std. Port.
Admixture, Type	.....	.....	.....	.....	Hyd. Lime
Cement, Lbs.	447	494	517	564	592
Admix., Lbs.	.....	.....	.....	.....	30
Sand, Lbs.	1323	1490	1424	1407	1260
Coarse Aggregate Lbs.					
½"	x	x	x	x	x
¾"	x	x	x	x	x
1"	1942	1700	x	x	x
1¼"	.....	.....	x	x	x
1½"	.....	.....	1940	1926	1827
2"	.....	.....	.....	.....	.....
2½"	.....	.....	.....	.....	.....
Water, Lbs. (total)	305	300	.....	324	302
Slump Range, Ins.	4–6	2–4	2–5	4–7	2–7
Water Gain	Slight	None	Slight	Heavy	Slight to very heavy
Pumpability	Good	Good	Good	Yes & no	Good to impossible
Dry Rodded Wt. c.f.					
Sand	112	107	106	.....	105
Large Aggregate	95	94	.....	.....	94
Specific Gravity					
Sand	2.63	2.67	.....	.....	2.62
Coarse Aggreg.	2.66	2.59	.....	.....	2.64
Ave. Comp. Strength (28 days)	3410 (7 da.)	3600	.....	.....	.....

TABLE II (Continued)

Sieve Size	Separate Material Gradations—Percent Passing				
2½"	....	....	....	....	....
2"	....	....	....	....	....
1½"	....	....	100	100	100
1¼"	....	....	....	....	....
1"	100	95	92	82	93
¾"	82	63	49	57	62
½"	....	55	15	17	37
⅜"	29	25	100	....	19
No. 4	9 100	3 100	2.4	1 98	4 99
No. 8	....	2 86	86	79	82
No. 16	61	64	....	64	59
No. 30	48	42	31	....	37
No. 50	12	16	15	10	20
No. 100	1	3	1.2	0.5	4
No. 200	....	0.5	....	....	....

Representative Crushed Stone Concrete Mixtures Placed By Pumpcrete

	6	7	8	9	10
Stone, Type	Quartzite	Trap	Trap	Limestome	Limestone
Sand, Type	Washed River	Washed River	Washed Bank	Great Lakes	L. I. Sound
Cement, Type	Std. Port.	Std. Port.	Std. Port.	Moderate	Std. Port.
Admixture, Type	.....	.....	.....	.....	.....
Cement, Lbs.	493	505	564	470	517
Admix., Lbs.	.....	.....	.....	.....	.....
Sand, Lbs.	1370	1530	1149	1115	1300
Coarse Aggregate, Lbs.					
½"	x	x	x	x	x
¾"	x	x	956	x	x
1"	x	1830	x	1130	1239
1¼"	x	.....	x	x	x
1½"	1920	.....	x	x	x
2"	.....	.....	1432	1150	852
2½"	.....	.....	.....	.....	.....
Water, Lbs. (total)	305	.....	269	256	274
Slump Range, Ins.	1–2	3–8	1½–3	1–2	3–5
Water Gain	Slight	Heavy	None	Slight to heavy	Slight
Pumpability	Poor	Good	Fair	Good	Good
Dry Rodded Wt. c.f.					
Sand	100	106	.....	.....	99
Small Coarse Agg.	.....	.....	.....	.....	99
Large Coarse Agg.	105	102	.....	.....	95
Specific Gravity					
Sand	2.60	2.65	.....	2.63	.....
Coarse Aggregate	2.83	2.80	2.80	2.79	2.79
Ave. Comp. Strength (28 days)	3200	.....	4750	4900	.....

Sieve Size	Separate Material Gradations—Percent Passing				
2½"	....	....	....	100	....
2"	....	....	95	95	100
1½"	100	100	89	36	80
1¼"	....	....	....	10	....
1"	89	97	41	4 98	21 98
¾"	57	59	35 98	64	7 78
½"	....	41	12 49	23	43
⅜"	18	10 100	....	11	2 27
No. 4	5 90	1 98	1 3 95	2 96	0.7 4 96
No. 8	77	79	65	....	86
No. 16	58	60	....	73	74
No. 30	29	36	34	....	54
No. 50	6	9	16	18	19
No. 100	1.5	1.5	1	2	3.5
No. 200	....	....	....	....	....

his setup to the opposite end for the last half, rather than try juggling proportions to improve the pressure resistant qualities of the concrete. The stone was very flat and somewhat bunched between the ½ and ¾ screens and the concrete was on the under-sanded side. It is believed a deficiency of natural fines in the sand, which was not compensated for by stone fines as is sometimes the case, contributed equally as much to the balkiness of this concrete when it was pumped beyond the 700 ft. marker.

5. The average grading shown for this stone is very misleading. It ranged widely from day to day, if not from hour to hour. The sand was a known quantity, having been pumped very successfully when combined with crushed aggregates on another job. Sometimes the concrete pumped beautifully at an equivalent length of 1100 to 1200 ft.; at other times, it could not be pumped 300 ft. without a radical change in the given design. The trouble was occasioned by the fact that the stone had been stock-piled by dumping down a high embankment several months previous to the start of the job. It was reworked by bulldozing from time to time as the job progressed. At times the mix would be approximately as shown and worked all right, then the crane loading the bins would hit a new spot in the stock pile, then all the stone would be one size, large or small and another 400 to 500 lbs. of sand and many gallons of water might be required for pumpability or workability.

The admixture indicated above was only used on those occasions when the concrete would suddenly develop a bad bleeding condition. The lime appeared to retard bleeding considerably.

6. Here is an example of an experienced organization making the grade under difficult pumping conditions. The sand was very harsh, with a deficiency of fines and bled profusely in a 3″ slump concrete. Bleeding, however was slight with dry concrete. The absorption of the stone is not known, but it must have been high. With the amount of sand shown above as the minimum for adequate workability, the stone produced a very low slump concrete with the maximum water cement ratio so that careful control of proportioning was required to meet a specified strength of 3000 lbs. Hourly production was always on the low side, but what concrete did get into the pipeline behaved itself.

7. This was a very flat-breaking trap rock and the sand bled copiously yet the concrete was satisfactory in every respect, giving maximum production at long ranges with any slump consistency. This is one of the exceptions to the usual rule that a badly bleeding concrete is almost a sure source of pipeline trouble when pumping at long ranges or where frequent shutdowns are in order.

It is assumed the exception occurs when the grading of the sand and cement is such that the latter will pass water freely, but is held in place by the sand so that it cannot be flushed or washed out of position along with the water. This is nothing other than assumption—there may be a more plausible explanation.

8. Too harsh, and aggregate too large for the 160 Pumpcrete. Production was always on the low side. The concrete would lay in the pipeline for hours without plugging and could be pumped long distances, even though it pumped very hard when down to a 1½″ slump. Another 100 lbs. of sand and enough water for a 3 to 4 in. slump would probably have stepped it up to a good capacity for the "160."

9. The sand here was very spottily graded, varying widely in all directions from the analysis given. Sand streaking in the forms was one reason the slump was held as low as shown, since cylinder breaks averaged 75% higher than the specified 28 day strength.

The concrete bled so badly with a little excess water that it might have caused some pipeline trouble (which never developed with the low slumps) had it been mixed to a sloppy consistency. Hourly production was consistently below normal with a 1 in. slump, but the pump would jump up above 60 yards per hour with enough water for a 3 in. slump.

10. This concrete was designed by Mr. A. T. Goldbeck for the express purpose of obtaining optimum pumpability. It was pumped far beyond recommended distances at a fairly high rate of production. The slump dropped as low as 1½ in. at times and went over 6 in. at others, but in the main it fell within the range shown.

Many thousands of yards of gravel aggregates were pumped on the same project in the early stages of construction. It is worthy of notice that the limestone was less abrasive and pumped better than the gravel when combined with the same sand and less cement. The stone was cleaner and more uniformly graded than the gravel, which probably accounted for this.

Design and Construction of Flight Strips[1]

By FRED SCHNEPFE

Special Engineering Consultant to the Administrator of the Federal Works Agency and Director of the Flight Strips Division, Public Roads Administration.

• Already, that new adjunct to the highway, the flight strip, has proven its merit as a safety measure for distressed planes. It, however, has other important functions and is now recognized as a necessary supplement to a rapidly expanding air force and to a future greatly augmented system of air transport. It is fitting, therefore, that some of the details of the design and construction of the flight strip be made known at this time.

SITE selection is of primary importance and since every site has its limitations, thorough investigation and good judgment are necessary to evaluate the advantages and disadvantages of a location.

In nearly every instance, the projects contained in the program submitted by the Army Air Force are designated by area rather than by exact location. Usually an area averaging approximately 100 square miles was shown on a map, any suitable location within the area being acceptable to the Army Air Forces. The latitude which this gave our engineers in selecting sites has made it possible not only to select good sites from a military viewpoint, but, everything being equal, to select sites that will have value after the war for use in civil aviation. Also, it has made it possible to select sites having the best approaches, terrain, soil and drainage conditions as well as proximity to sources of materials and transportation. The effect of these considerations on initial cost and recurring maintenance costs as well as on operational and safety characteristics is obvious.

Each Flight Strip area with its particular topography, drainage, soil, materials for surfacing runways, and other local conditions present a different problem when the selection of site is considered. Information on factors which directly affect operations such as meteorological conditions, direction of the prevailing winds, freedom from surrounding obstructions and other related data must be obtained. Other factors include alignment with respect to approach areas, location with respect to drainage, speed and cost of construction, and accessibility to means of communication and transportation facilities.

In the selection of a Flight Strip site, investigation of suitable construction material on or near the site should be made for economy in first cost and subsequent maintenance. The fact that gravel, sand or stone deposits are available at or near a proposed site may well influence the decision in favor of that site provided the soil and aeronautical features are suitable.

[1] Abstract of a paper presented Oct. 15 at the fall meeting of the American Society of Civil Engineers.

Since Flight Strips have only one runway, it is of particular importance that they be located in the direction of the prevailing winds. This should include "wind-rose" charts and information on fog and smoke conditions affecting general visibility in the vicinity. Sites must be selected where nearby obstructions are not of sufficient height to create hazards, or where provisions may be made for their removal.

Geometric Design

The geometric or dimensional design of the Flight Strip itself is based largely on the operational needs of expected traffic and relates to vertical, horizontal and side clearances, including the length and width of runways, shoulders and end zones as well as approach zone areas.

The approach zone to a Flight Strip runway is a trapezoidal area 500 feet wide at the end of the runway extended, and 4,000 feet wide at the zone limit 2 miles distant. Within this trapezoidal area no obstacles, either natural or man-made, may be permitted which are high enough to stand above a 30 to 1 glide angle projected from the end of the runway extension, and wherever feasible a 40 to 1 glide angle is adopted. In addition to the clearances provided at the approach zones, clearance is required along either side of the Flight Strip and extending above a plane projected on a 7 to 1 slope from the edge of the runway and runway extensions for a zone width of at least 500 feet.

The over-all dimensions of the Flight Strips designed for military use include a normal length of 8,000 feet. However, there may be occasions in which a particularly good site may fall short of this. Such cases, of course, require special consideration. In general the total width of these Flight Strips is not

less than 500 feet nor more than 1,000 feet. Nearly all of the present designs call for a width of 500 feet. The paved runway has a width of 150 feet and a length of 4,000 feet at sea level. This is increased for higher altitudes ranging from 4,000 feet at sea level to a length of 8,000 feet at an altitude of 8,000 feet.

At each end of the paved runway there is a "runway extension" of the same width as the paved runway, usually consisting of some form of soil stabilization. The purpose of these extensions is to provide additional runway length, at low cost, for the planes that may require a runway longer than that which is paved. The shoulders on either side of the paved runway have a width of 175 feet and extend for the entire length of the paved runway and runway extensions. On certain projects portions of the shoulder areas for a length of 6,000 feet (at sea level) are stabilized, surface treated with bituminous material, or turfed.

Runway and shoulder grades are relatively flat. The maximum transverse runway grade is 1½ percent, with a minimum slope of 1 percent. The one percent transverse grade is considered the more desirable. Runways may have one-way or two-way transverse slopes. Where a two-way slope is used the surface is made up of two intersecting planes. Parabolic or circular crowns are not used. This is to avoid the possibility of water standing in the central and most used portion of the runway. The maximum transverse slope of shoulders is one percent, with a minimum desirable slope of five-tenths of one percent. In no case do shoulders slope towards the runway. The maximum longitudinal grade of runways is 1½ percent. However, if feasible, one percent should not be exceeded. A considerable number of projects have an unbroken longitudinal grade throughout the runway and runway extensions. Where changes in grade are used the maximum rate of change is ½ percent per 100-foot station. Vertical curves preferably have a length of 500 feet with a desirable minimum of 300 feet. Every effort is made to obtain longitudinal tangent intervals between vertical curves of not less than 1,000 feet. Sight distances along the runways are so designed as to permit an unobstructed view for their entire length as determined from a pilot's eye at an elevation approximately 10 feet above the runway surface.

Structural Design

Structural designs relate largely to the type of surfacing used on runways and shoulders to accommodate expected traffic. An important consideration is to design a subgrade of sufficient and uniform bearing power. At each location soil studies are conducted to determine the bearing values of the natural subgrades. Any deficiencies are corrected before pavement construction is undertaken. The thickness of the prepared subgrade will depend directly on the maximum loads it is to support and the bearing value of the material used in its preparation and indirectly on climatic conditions.

In no case are designs for runway pavements based on a wheel load of less than 12,500 lbs. In all cases they are safe for much greater loads or easily may be strengthened to carry the heaviest planes.

Impact

For a number of years it was standard practice to add an impact factor to the static wheel load. Now it is believed that the critical load may be that imposed by the wheels of the standard plane rather than the sudden forces developed during operating maneuvers. The force exerted against a runway pavement by the wheels of a standing airplane can be determined without difficulty but when a plane is in motion, either in preparing to take off or as the wheels make contact in landing, the force developed by the wheels on the runway is very difficult to determine. It has been observed that surfaces of the flexible type, including the various bituminous treatments which satisfactorily sustain the weight of standing airplanes, do not fail structurally under the forces developed by the same airplanes in motion. Consequently, at the present time there is a definite trend away from the use of any impact factor whatever.

The maximum wheel load of the airplanes of today is several times greater than the maximum wheel load permitted by law on highways. The size of the tire used on the landing wheels of airplanes is correspondingly greater than those used on motor vehicles. There are other important differences between the motor vehicle and the airplane with respect to their effects on pavements. For example, the time duration of stress from dynamic loading is probably appreciably less in a runway than it is in a highway, and finally, the frequency of load repetition at a given point in a highway pavement is much greater than on a Flight Strip. Consequently, it seems unnecessary to consider fatigue of the concrete as a factor in structural design of rigid pavements for Flight Strips.

The structural strength of a given type of pave-

ment is dependent on its thickness and support. For flexible type surfaces the thickness of the wearing surface, base course, and subbase considered as a unit, are predicated in part on the observed behavior of soils in highway and airport construction, and in part on such results of research as are available. Quite recently the Public Roads Administration published an article entitled "Classification of Soils and Control Procedures Used in Construction of Embankment," which may be used as a guide in studying soil characteristics and their classification as related to thickness of flexible type pavements. For a number of years the State Highway Department of California has investigated the design and service of flexible type pavements on highways in that State and they have developed a method of designing the bearing capacity of flexible type pavements which satisfactorily has met their needs. In June of this year the War Department, Office of the Chief of Engineers, published Chapter XX of their engineering manual entitled "Design of Runways, Aprons, and Taxiways at Army Air Force Stations." The brochure contains curves, illustrations, and data for designing flexible type pavements based on the theory and practice developed in the State of California. It seems likely that this brochure and the methods developed in California will go a long way toward clarifying the design principles as applied to flexible type pavements. The thickness of such surfaces will, of course, depend largely on the character of the material used in their construction and the bearing power of the subgrade on which they rest. For the heavier wheel loads and the soils of low bearing value a total thickness of as much as 24 or 30 inches may be required, whereas for the lighter loads, higher type surfaces and soils of high bearing value as little as 6 to 10 inches total thickness may be adequate. Bituminous wearing courses on flexible bases are seldom less than 2 inches in thickness.

Engineers are in agreement that during the emergency the use of steel in concrete pavements should be limited to the minimum compatible with sound engineering procedure. This policy is being adhered to in the Flight Strips program.

Drainage

Drainage of Flight Strips is a major problem, but a relatively simple one when compared with the drainage of airports having a number of intersecting runways. On many airports subdrainage structures must be provided to intercept and remove storm water, to drain water from seepage planes in the soil and to lower the water table. In such cases drainage becomes an important factor in the cost of airport construction. In the case of Flight Strips the problem is considerably simplified and drainage structures may be entirely eliminated or used only to a minor extent. On them, runoff resulting from rainfall or melting snow flows across the runway pavement and shoulders to shallow open ditches along the outer edges of the area.

Where storm drains or subdrains are needed along the edges of runways, open joint or equally suitable pipe is placed in a trench and backfilled with gravel or crushed stone to a point 12 inches below the top of the trench. The top 12 inches is composed of coarse stone premixed with bituminous material firmly tamped or rolled into place. This prevents displacement by wheels and the blast of propellers and serves also as a transition strip for aircraft passing from the relatively rigid runway to the softer shoulders.

Shoulders

Shoulders adjoining the paved runway of a Flight Strip vary from a normal highway shoulder and must be treated accordingly. While the shoulder in no case should be less than 150 feet wide, it is not always necessary that mechanical stabilization be carried the entire width; ordinarily, stabilizing would be carried from about 75 to 100 feet from the edge of the runway. The shoulders of Flight Strips bear the same relation to the paved runway that the shoulders of a road bear to the paved roadway. Shoulders are primarily "run-over" areas and the portions adjacent to the runway will have more traffic than distant portions. It is, therefore, apparent that the greatest stabilization should be adjacent to the paved runway and may decrease from that point to zero as the ditch line is approached. Generally, a uniform depth extending from the edge of the runway across the shoulder for a width of 50 to 75 feet and then decreasing as it approaches the outer edge of the shoulder will be found suitable.

Over stabilized and unstabilized areas it is frequently desirable to either seed or sprig when the

soil and general weather conditions are such that grass will grow. Where grass will not grow an application of a bituminous dust layer may be used. Where shoulders, runway, and runway extensions are surfaced or treated with bituminous material there should be a stripe painted around the runway to distinguish it from less substantial areas. Runway visibility may also be obtained by using a finish of light color aggregate on bituminous surfaces.

Fences

In some instances fencing is erected at boundaries of Flight Strip areas to prevent hazards to aircraft from grazing animals and trespassers.

Construction Methods

The principal construction operations are clearing and grubbing, grading, drainage and paving. Of these items, grading and paving are the most expensive, consume most of the time and are most important to the successful operation of the Flight Strip.

A large portion of the Flight Strip area is composed of embankment. During the emergency runway pavements are likely to be placed immediately, or shortly after the embankment has been completed. Therefore, every effort should be made to secure optimum compaction to fill material and thus avoid subsequent settlement and damage to pavement.

Construction of Pavement

Methods used in the construction of flexible type bases and surfaces follow those developed by the State highway departments in cooperation with the Public Roads Administration, and they represent best current practice. A number of types of bituminous surfaces can be satisfactorily constructed with local aggregates. Examples are sand asphalt pavement and several types of open and dense graded bituminous mixtures. One type commonly used on Flight Strips is the plant mixed bituminous surface laid to a minimum compacted thickness of 2 inches. Other acceptable types are extra heavy surface treatments not less than 1½ inches in thickness for relatively light traffic, penetration macadam, roadmix, or mixed-in-place surfaces. These pavements are well known and a description of them is not considered essential.

T. Ward Havely

THE many friends of T. Ward Havely, President of the Central Rock Company, Lexington, Kentucky, will be deeply shocked to learn of his untimely death on March 22.

As a member of the Board of Directors of the National Crushed Stone Association since his election in January 1940, Ward Havely gave generously and enthusiastically of his time and energy. His loyal support of organized effort in the crushed stone industry did much to advance the interests of the Association in the territory in which he operated.

Ward Havely was prominently identified with the civic affairs of his community. He served several years as President of the Blue Grass Automobile Club and took part in various good-road movements promoted by that organization. In 1939 he became Mayor of Lexington and during his tenure of office was instrumental in obtaining Federal approval for the construction of a new city-county airport. He also assisted in obtaining the establishment of the Lexington Signal Depot at Avon and several wartime industries in Lexington. He supervised the setting up of civilian defense activities in Lexington at the outset of the war, and this year instituted a drive against vice conditions. The Optimist Cup, awarded annually by the Lexington Optimist Club, was presented to him on February 5, as the outstanding citizen of 1942.

Tests on a Special Type of Double Surface Treatment

By A. T. GOLDBECK

Engineering Director,
National Crushed Stone Association.

• **It is important that road maintenance be continued even though new road construction must be stopped temporarily. Research has indicated excellent results with the method of double-surface treating concrete roads, as described in the present article.**

IN SEPTEMBER 1942 a series of experimental surface treatment sections involving both single and double surface treatments was constructed on an old concrete pavement under the writer's technical direction. Section 11 of these experiments was somewhat out of the ordinary in that it required the spreading of an incomplete cover of large size stone (½ to 1 in.) on the concrete base before applying the bitumen. Specifically this section was constructed as follows:

First spread 20 lb. of ½ to 1-in. stone on the concrete base, then treat with .35 gal. of tar, then cover with 20 lb. of ¼ to ½-in. stone, roll lightly (one to two passes of the roller) then treat with .15 gal. of tar and cover with 10 lb. of ⅛ to ¼-in. stone and finally roll to obtain maximum density, but without crushing the stone (ten to twelve passes of the roller).

The above method produced a surface much resembling cold laid bituminous concrete and in view of circumstances which prevented a thorough preliminary investigation of the correct relative quantities of these respective stone sizes and quantities of tar before laying the test sections, it seemed desirable to conduct further laboratory experiments in an effort to arrive at the most desirable quantities to use in construction of this nature. Accordingly, additional test sections were constructed in the circular track of the National Crushed Stone Association using a high grade of limestone from Martinsburg, W. Va., separated into 3 sizes as follows:

Total percent passing—	½ to 1 in.	¼ to ½ in.	⅛ to ¼ in.
1 inch	100	—	—
¾	54	—	—
½	8	100	—
⅜	4	54	—
#3	0	8	100
4	—	4	54
8	—	0	8
50	—	—	0

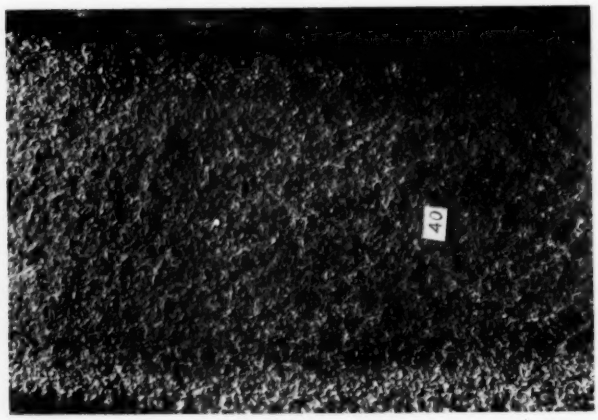
A cutback asphalt of RC-5 grade was used.

It is quite obvious that if too little of the ½-to-1-in. stone is used on the base course, there will be a large volume of surface voids to be later filled with the ¼-to-½-in. stone and if there is insufficient ¼-to-½-in. stone used, the large size base course stone will project above the level of the filling material and the roller consequently will ride on these projecting points and will insufficiently compact the ¼-to-½-in. filling material. It would seem desirable to somewhat overfill the voids in the ½-to-1-in. stone so that the roller will compact the small stone in those voids. The present laboratory tests seem to indicate that when 30 lb. of ½-to-1-in. stone was used, 30 lb. of ¼-to-½-in. stone is necessary to accomplish the above purpose.

Still another point that needed investigation was the question of what should be the relative amounts of bitumen to be used in the first and in the second pour. In the first place, there should be enough bitumen used to thoroughly coat the concrete base which is exposed between the ½-to-1-in. stone and there should be sufficient bitumen left over to run under that stone, if not immediately, then at least in the course of time. It also is obvious that if a large proportion of bituminous material is used to cover the ½-to-1-in. stone on the base, then to properly penetrate the cover of ¼-to-½-in. stone, the bitumen would have to move upward. It seems more logical to use a relatively small amount of bitumen in the first pour and a larger amount in the second pour to cover the ¼-to-½-in. stone used as a filling material. This relatively large amount of bitumen on the ¼-to-½-in. stone will then penetrate downward and will become effective as a binding medium. If, on the other hand, the bitumen is forced to penetrate upward, there is danger of displacement of the ¼-to-½-in. stone due to the action of traffic until such time as upward penetration of the bitumen has occurred. Sections Nos. 1, 2 and 3 were aimed at investigating this particular point, the effect of different quantities of bitumen in the first and second pours.

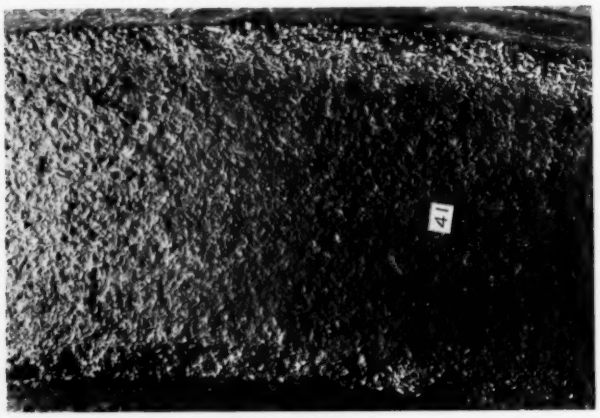
It also seemed to be desirable to investigate the question of whether any better results would be obtained by a complete coverage of base course before applying any stone. Sections 4, 5 and 6 were built with this particular aim in view.

After Final Compaction by Traffic (10,000 passes)

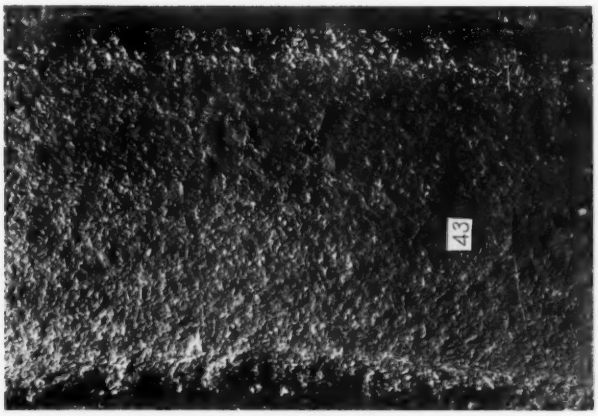


Sections Nos. 1 and 2

Section No. 5



Section No. 4



Section No. 6

TABLE NO. 1

Section No.		1	2	3	4	5	6
RC-5	gal./sq.yd.	—	—	—	0.2	0.2	0.2
No. 2 stone	lb./sq.yd.	30.	30.	30.	30.	35.	35.
RC-5	gal./sq.yd.	0.3	0.2	0.4	—	—	—
No. 1 stone	lb./sq.yd.	30.	30.	30.	30.	25.	25.
RC-5	gal./sq.yd.	0.3	0.4	0.2	0.4	0.4	0.5
No. 1A stone	lb./sq.yd.	11.	11.	11.	11.	11.	11.

The six test sections described in the above table No. 1 were laid in the circular track of the National Crushed Stone Association and were cured for 11 days. Finally, they were given 10,000 passes of a 1900-lb. loaded rubber-tired wheel which was moved laterally across the track from time to time to different paths in order to give equal traffic to the entire width of the sections. Finally, after this action of the rubber-tired wheel on the track in a dry condition, the track was covered with water and the wheel was operated in a *single* path 10,000 times without the use of tire chains. The track was maintained at room temperature. The effect of the wheel on the wet track running in a single path is to cause rutting, the amount of the rut being an index of the relative durability of the respective sections. This *rutting* produced by the above action was as follows:

TABLE NO. 2

Section	Rutting in Inches
1	0.14
2	0.12
3	0.14
4	0.14
5	0.12
6	0.15

It will be noted in the above table No. 2 that there is no significant difference in any of the sections as far as rutting is concerned. There was, however, a difference in appearance of the test sections after they were submitted to the action of traffic when the track was in a dry condition. It will be noted, for illustration, that the appearance of sections 5 and 6 indicates that there is much more of the ½-to-1-in. base course stone showing through the surface than in the other sections. It is believed that these two sections, Nos. 5 and 6, are unnecessarily jagged and rough. No doubt this was due to the fact that less ¼-to-½-in. stone was used as a filler in these two sections than in the other sections. There was nothing indicated by the tests to even suggest that the procedure of applying the large-size stone on the base first before applying the asphalt is not an entirely satisfactory procedure, provided the proper quantities of respective materials are used.

On the basis of uniformity of appearance at the end of the test, Section No. 2 seemed to be the best Section with Section No. 1 as the next best. Sections 5 and 6 had insufficient ¼-to-½-in. stone to properly fill the voids between the ½-to-1-in. stone and consequently the ½-to-1-in. stone projects above the surface and creates excessive roughness. As the result of these experiments, it is recommended that a double surface treatment which should give excellent results both as to uniformity of appearance and durability may be constructed as follows:

Recommended Sequence of Operation

1. First spread in a uniform manner 30 lb. per sq. yd. of ½-to-1-in.-size stone.
2. Treat with .2 to .3 gal. per sq. yd. of RC-5, or equivalent tar.
3. Spread uniformly 30 lb. per sq. yd. of ¼-to-½-in. stone.
4. Roll very lightly (about one or two passes).
5. Treat with .3 to .4 gal. per sq. yd. of RC-5, or equivalent tar.
6. Cover with 10 lb. per sq. yd. of ⅛-to-¼-in. size.
7. Roll until adequate compaction is obtained, but not to the extent of crushing the aggregate excessively (about 10 to 12 passes of the roller).

* * * * *

The above method of double surface treatment has the following advantages:

1. It is carried out over a given stretch of road while all the equipment is there because each operation follows the preceding one immediately.
2. The surface voids in each course are choked with smaller stone and this aids stability.
3. There is no waste of material due to traffic and thus it is all effective and the proper balance between the quantity of stone and quantity of bitumen is not disturbed as may happen when the stone is thrown off the road by traffic.
4. No undue crushing of the stone takes place because it is cushioned by the bitumen.
5. A smooth, non-skid surface is built up which should maintain its non-skid characteristics.

Correction

We are indebted to Prof. Duff A. Abrams for recently calling to our attention an error which occurred in the article by Mr. Goldbeck and Mr. Gray appearing in the May-June, 1942 issue of the CRUSHED STONE JOURNAL. On page five, Prof. Abrams was quoted as follows:

> "With given concrete materials and conditions of test the quantity of mixing water used determines the strength of the concrete as long as the mix is of a workable consistency."

The last word in the above quotation should have been "plasticity" instead of "consistency."

★ ★
IF IT HASN'T BEEN USED FOR THREE MONTHS, AND IF SOMEONE CAN'T PROVE THAT IT'S GOING TO BE USED IN THE NEXT THREE MONTHS—
FIND A USE FOR IT—OR SCRAP IT!
★ ★

Gone With the Winter![1]

THIS paraphrasing of the title of the current "best seller" vividly expresses the plight of hundreds of miles of low-cost, black top roads on both our county and state highway systems, following the final exit of frost from the subgrades. This is not only true in Indiana but of course is applicable to other states where low winter temperatures prevail. We wonder how long the bill-paying motorist will continue to be patient and placidly view this annual winter and spring destruction of these bituminous roads without raising his voice in protest.

This Editor is a firm believer in the economy and practicability of low-cost bituminous road surfaces *provided* they are constructed on roads carrying a reasonable amount of traffic and *providing* that thorough advanced preparation has been made to insure the adequate functioning of this type of wearing surface.

It is just as asinine to build one of these cheap low-cost bituminous roads expecting it to carry heavy traffic as it is to build a high-type, costly concrete or brick road where the traffic never has or never will exceed two or three hundred vehicles per day.

Our biggest blunder is in going out slapping down a coating of bituminous material on any old gravel or stone road regardless of the *thickness* and width of the metal, the shape of the surface, the width of right-of-way, the condition of drainage, and other important items.

It is our contention that in most cases no bituminous material should be placed on any gravel or stone road until a year after decision has been made to black-top said road. Once the decision is reached an earnest attempt should be made to secure an adequate right-of-way for an investment of this kind. If enough right-of-way cannot be obtained, the project should be abandoned immediately. The motorists are not providing millions of dollars each year to build "horse and buggy" roads, and that is the only kind of road that can be built in the famous 32-foot right-of-way. Once the right-of-way is secured, a heavy grading outfit should be set to work opening new drainage ditches back near the right-of-way line, shaping up wide shoulders which slope gradually into the side ditches, eliminating short sight distances in both vertical and horizontal curves, and widening all narrow fills. Culverts should be lengthened to clear the shoulders and all telephone poles should be moved back to the new fence line.

Next, the roads should be examined to determine, the thickness of the road metal and new gravel or stone should be added wherever needed to build the road up to a *minimum* of eight inches of compacted material. We are paying dearly in excessive repair costs on bituminous surface treated roads on a base of four inches or less of gravel. This surface should be properly shaped and adequately maintained throughout the fall, winter, and spring so that it may consolidate under traffic to the proper cross-section without excessive crown and with no warped surface sections.

Then, when we are assured that the road is *ready*, the bituminous material should be applied, preferably in June or July, so that there will be ample time during several successive weeks of hot weather for the bituminous material to "bleed up" and completely seal the surface. One of the prime causes of failures in our bituminous surfaces is treating the surface late in the fall when it is too cold and damp to even expect decent results.

Proper and *prompt* patching of all surface breaks would greatly reduce the severe surface destruction occurring in winter. Recently we traveled over about ten miles of a low-cost bituminous road, retreated just last fall, that was thoroughly covered with surface and base breaks. Two patching crews were working industriously on repairs but we failed to see in the ten-mile strip any indications whatever of the installation of subdrains to prevent base breaks occurring at the same places next spring.

Additional Comments, as of 1943

While the preceding article deals primarily with low-cost bituminous surfaces, we have ample evidence that concrete and other high-type pavements also are susceptible to the destructive effects of spring thaws. The winter and early spring seasons this year, involving low temperatures and several alternate freezing and thawing periods, have provided ideal conditions for one of the most severe breakups our highways have eperienced for a num-

[1] Reprinted from the March issue of *"Highway Extension News,"* issued by the Engineering Extension Department, Purdue University.

ber of years. This condition is no respecter of "persons" or "pavements" since both state and county roads (bituminous as well as high-type pavements) are showing evidences of severe destruction under fairly heavy traffic as the frost leaves the subgrade. City streets are not immune to this type of destruction.

Much observation and research has been centered on this troublesome spring breakup in attempts to determine the causes and to devise remedies. Much has been learned, but we still have a long way to go before all of the questions involved are satisfactorily answered. Undoubtedly, water is *Public Enemy No. 1* in these annual spring breakups. With no water in the subgrades there would be no frost heaving and no release of free water when the frost leaves the subgrade. There may be some thawing of the frost-zone from the bottom up, but this is minor in comparison to the rate of thawing from the top down. As the top layers of the frost-zone thaw, free water is released which cannot escape downward through the still frozen layers, and in most cases the shoulders are protected longer in a frozen condition by a layer of sod so that this free water cannot escape laterally to the side ditches. The kneeding action of traffic produces a soft, mushy layer of subgrade material which is readily distorted under traffic loads permitting considerable movement and wave action in the wearing surface resulting in rapid disintegration.

Melting snows or rainfall on these broken surfaces simply adds more water to the soft subgrade, intensifying the difficulties. This year many bituminous surfaces have been almost completely destroyed and we have had cases where concrete pavements under excessively heavy traffic have broken up into small sections which have been displaced by traffic and in some cases have been forced up on edge until traffic had to be detoured.

Numerous attempts have been made to stabilize subgrades to prevent such damaging developments at widely divergent costs and with varying degrees of success. Some of these have involved the use of admixtures in the subgrade such as bituminous materials, portland cement, granular materials, salts, etc. Subdrainage installations have been satisfactory in many cases, while with certain types of heavy clay soils they have been useless. Naturally the type of soil in the subgrade is a major factor in this question of stability.

Where subgrade stabilization is not attempted, a granular base course of adequate thickness to carry the traffic when the subgrade is soft is absolutely necessary. Too long we have skimped on the thickness of this base course in order to hold down the total cost of the road. Frequently, what little we have saved in first cost has been squandered, many times over, in repair and maintenance operations chargeable largely to the skimpy base course. It may be that if, instead of providing 6 or 8 inches of gravel or stone base for these secondary roads, we would go to 12 or 18 inches we might secure a strong, compacted base on which a bituminous surface could be placed with some assurance that it would not break up in the spring. Porous drains from these granular base courses through the shoulders to the side ditches, at reasonable spacing, are beneficial.

It has been our observation that a compacted crusher-run limestone base (with the dust left in) provides greater load carrying value than gravel of corresponding thickness. This apparently is due to the interlocking effects of the angular stone particles and to the cementing action of the limestone dust when water is added. There are many examples of low-cost bituminous surfaces on adequate stone bases in Indiana which have never been damaged by frost action.

We take off our hat to the highway engineers in some of the New England states and also in Oregon on the West Coast who have had the wisdom and the courage to specify base courses of pit-run gravel from 12 to 24 inches in depth under all concrete pavements. Instead of stopping these base layers at the pavement edges, they are continued out through the shoulders to the side ditches so that water collecting under the pavement can be drained out to the ditches. The placing of a 6- or 8-inch layer of sand or gravel under the pavement section *only*, undoubtedly will contribute something to stability, yet it certainly provides a *reservoir* for water which cannot escape through impervious shoulders to the side ditches. Some of the states mentioned above have reported costs of around $3,000 per mile for this porous subbase. Even if such a base course would cost $5,000 a mile it would be money well

spent in adding several years to the life of a $20,000 pavement and in reducing the annual maintenance cost thereon.

Almost 30 years ago, Professor Stephen Taber, at the University of South Carolina, began an investigation of soil freezing and frost heaving and in 1916 and 1918 published his theory of surface heaving caused by segregation of water forming ice crystals. From 1929 to 1932 additional articles dealing with the subject of frost heaving were published by Professor Taber. His work has been taken up and carried on by various investigators and much printed data is now available on this subject. To those interested, we recommend "Frost Action in Highway Bases and Subgrades" by H. F. Winn and Professor P. C. Rutledge of Purdue University. This is Highway Research Bulletin No. 4, published in 1940. A limited number of copies are still available. They can be obtained by writing to The Joint Highway Research Project, Civil Engineering Building, Purdue University, Lafayette, Indiana.

Several members of the staff of our Joint Highway Research Project have been making rather extensive surveys of frost-damaged roads in various parts of the State during the current breakup. Subgrades have been dug into, samples have been collected for laboratory analysis and from various measurements and visual inspection considerable data has been secured from which it is hoped much additional light will be thrown on the causes of various types of breakups and some possible remedies determined.

This is one of the most serious problems facing highway men at the present time and it is hoped that workable and not too costly solutions of the problem will evolve soon so that the major share of this added annual maintenance expense can be eliminated.

Bernard E. Gray Appointed General Manager of the Asphalt Institute

AT THE annual meeting of the Board of Directors of the Institute, Bernard E. Gray was promoted to the position of General Manager—adding the duties of that office to those already held as Chief Engineer —with the title of General Manager and Chief Engineer. Mr. Gray has been with the Institute for the past thirteen years, successively as Highway Engineer, Chief Highway Engineer and Chief Engineer.

Warn Your Workmen Not to Leave Blasting Caps Around—They Are a Real Danger to Children

EACH year there are numbers of children, under the age of sixteen, who are injured, and in some instances, killed, from playing with blasting caps.

In 1926 the Institute of Makers of Explosives, a trade association comprising manufacturers of commercial explosives, took the matter up and began a vigorous movement to arouse public sentiment in the hope that parents, teachers, and all others who had children in their care, would cooperate in safeguarding boys and girls by instructing them concerning the dangers of playing with blasting caps.

Reports show that the most common types of accidents are from striking the caps with a hammer or stone. Any blasting cap will explode if it is hit hard enough with such instruments. Accidents are caused in large measure also by holding lighted matches to the caps. Picking out the explosive with a pin or nail also causes many injuries.

Blasting caps are detonators used for firing high explosives. They are loaded with a very sensitive and powerful explosive. One type is a small metal cylinder closed at one end and usually made of copper, although other metals are also used. This type is designed to be exploded by sparks from a fuse. Another type is known as an Electric Blasting Cap. This is also a metallic cylinder which may vary in dimensions and color. This type always has wires attached, sealed in with sulfur, rubber, or similar materials. A very small amount of current, even that supplied by an ordinary flash light battery, is sufficient to explode a single cap. Therefore, the wires from an Electric Blasting Cap may not be connected to a source of current without the danger of exploding the cap. Both types are also sensitive to impact with a hammer or stone and to fire applied to the metal cylinder.

These detonators are necessary in the use of dynamite. The caps get into the hands of children through the carelessness of users. Workmen leave them around following blasting operations. Sometimes they are carried home by workers and left about where children can find them.

Children and others inexperienced with explosives should not touch a blasting cap. It should be allowed to remain where found until an officer of the law or other responsible adult can be located.

Coal Dust[1]

It Causes Explosions and Pre-disposes Workmen to Disease

By R. R. SAYRES

Director, U. S. Bureau of Mines;
Member A.I.M.E.

• **Rock-dusting of coal mines has long been recognized as an effective means of reducing the danger of explosions from coal dust. Timely emphasis has been given to this fact in the following article.**

TWO serious hazards from coal dust confront the bituminous-coal miner—a physical or safety hazard and a physiological or health hazard. The first threatens the miner with loss of life from coal-dust explosions, and the second with loss of health and earning capacity from inhaling large quantities of the dust. Studies by the Bureau of Mines have shown that coal dust, except some grades of anthracite dust, is capable of initiating an explosion when no explosive gas is present and that its property of extending or propagating an explosion has been responsible for nearly all the widespread explosions that have occurred in bituminous mines in the United States in the present century. For years many mining people believed that low-volatile coal dust was not explosive, but not only is it explosive but if the source of ignition is intense, it is as explosive as the dust of many high-volatile coals. Because the war is creating increased pressure for greater coal production and because of the trend toward greater mechanization in mines, explosion and health hazards from coal dust are likely to increase considerably.

As an Explosion Hazard

Bureau of Mines data showed that 8378 miners were killed by gas or dust explosions in the bituminous-coal mines of the United States during the period 1906-40. During 1940 the toll from this cause was 290 fatalities. During the two fiscal years (July 1, 1939 to June 30, 1941) more men (379) were killed by explosions than the total number killed from the same cause during the preceding six years (368). No doubt many of these fatalities resulted from dust explosions alone and from gas and dust explosions combined. That this is probably true is indicated by data collected from various sources on 81 coal-mine disasters in which ten or more men were killed during the period 1839-1923. Of the 7916 fatalities from these 81 disasters, 2342 were ascribed to dust explosions alone—thus indicating that the physical hazard of coal dust in bituminous mines is a serious one.

An explosion hazard exists in dusty mines where coals contain more than 10 per cent volatile combustible matter; these coals include bituminous, semibituminous, subbituminous, and various types of lignite coals. The Bureau of Mines designates as "coal dust," material that passes through a 20-mesh screen. The explosibility of the dust is proportionate to the percentage that will pass through screens of finer mesh, especially 100-mesh and 200-mesh sizes. As the proportion of fine material in coal dust decreases, ignition becomes increasingly difficult, but after an explosion has a good start, particles barely passing a 20-mesh sieve and even larger will participate in extending the explosion.

A dust cloud of finely divided bituminous coal in the amount of 0.05 of an ounce of coal dust per cubic foot of air will propagate or extend an explosion; this amount is less than 4 oz. of coal dust to the linear foot of ordinary coal-mine entry. In practically all coal mines several times this amount of dust may be thrown into the air.

The fine dust which has lodged on ribs, roof, timbers, and floor in virtually every bituminous coal mine is particularly hazardous. Such settled dust is constantly a potential medium for initiation and propagation of explosions, for not only is it generally extremely fine (frequently more than 75 per cent of it will pass through 200 mesh) but also anything that dislodges this dust tends immediately to mix it intimately with the air to form the dust-air cloud that is necessary before dust can be exploded.

Means of igniting coal dust are present in all our bituminous and lignitic mines, either in the form of open lights or electric arcs, or through the use of black blasting powder or dynamite, or misuse of permissible or other explosives in firing with fuse, or in the employment of so-called bulldozing, adobe, or sand-blasting shots.

Mechanical mining of coal naturally produces larger amounts of fine coal dust than do hand-load-

[1] Presented at joint meeting of the mineral industries section, Engineers Society of Western Pennsylvania, and Pittsburgh Section, A.I.M.E., Pittsburgh, March 12, 1942. Reprinted from January issue of *"Mining and Metallurgy."*

ing methods; therefore, the need for allaying the dust at its source is greater, and if more adequate measures are not taken in the future to remove the hazards from dust in the coal mines of the United States, the industry ultimately will have a heavy bill to pay, not only in connection with explosions but also as health compensation.

Minimizing the Dust Hazard

Air dustiness in bituminous coal mines can be remedied by preventing the formation of dust at the source, so far as possible; at the same time adequate ventilation should be provided to dilute and remove any gas that may be present. The two principal methods used to minimize the explosion hazard of dust in the coal mines of the United States are control of the dust at point of origin, or watering, with or without wetting agents, and reduction of combustibility of the dust by rock-dusting. Some experimental work also has been done on the use of exhaust or suction methods to remove dust from coal-mine surfaces and mining equipment.

Although really efficient rock-dusting probably has been done in fewer than 100 of the approximately 6000 larger coal mines, and has not been done at all in more than two thirds of the coal mines of the United States, nevertheless it has had a decidedly important effect in diminishing the severity of explosions of gas and dust. Presence of explosive gas in the mine air increases the amount of inert matter required to make coal dust nonexplosive. Tests have indicated that the minimum incombustible content of mine dust should be increased 1 per cent for each 0.1 per cent of methane gas in the air current. Unfortunately many mine operators do not believe that nongassy mines need to be rock-dusted, and at the same time decline to consider a mine gassy unless explosive gas can be detected with a flame safety lamp. The fallacy of this conception has been proved by the fact that many gas explosions have occurred in so-called non-gassy mines, and this is to be expected since the ignition of as small a quantity as 150 cu. ft. of an explosive mixture of methane and air may under some circumstances precipitate an explosion which will sweep through a mine. An explosion initiated by methane generally has a much more violent start or "kick" than one originating from dust alone, and this violence tends to cause the formation of dust-air clouds whose ignition promotes explosions. Fairly accurate data taken from studies of individual coal-mine disasters indicate that rock-dusting in the coal mines of the United States for the past ten years or more has reduced the loss of lives by at least 200 a year. This saving in mortality has been accomplished notwithstanding the fact that only eleven of our 26 coal-producing states have any requirements as to rock-dusting, fewer than 2 per cent of the larger coal mines of the United States can be considered as being adequately rock-dusted, and few if any of the thousands of small mines use rock dust.

Although the value of rock-dusting as a means of minimizing the explosion hazard of coal dust is being more widely acknowledged each year, the use of water at and around working faces and on the floor of main haulageways as a means of allaying coal dust is gaining adherents relatively slowly. Steps to install such systems have not been taken by some mine officials because they think the amount of water required would be excessive and the added water would be detrimental to the sale of this coal and also under some conditions would be detrimental to the roof or floor in the mine. An attempt has been made to meet these objections by the proposal to use wetting agents other than water. (By the term "wetting agents" in the following paragraphs, those other than water will be meant.—*Ed.*) Such wetting agents have been used for many years, principally in the textile industry and in metallurgical and milling processes. Two types of mixtures are employed—one in which the ingredient forms an emulsion and the other in which the agent mixes intimately with water.

One of the claims made is that wetting agents will greatly reduce the quantity of water required to allay dust, a claim that has been substantiated by tests. Certain agents probably will require only a half or a third as much liquid as water alone. During one test in which a wetting agent was used with the water, dust at a discharge point in a tipple was reduced about 70 per cent, and the amount of water used was reduced about the same percentage, thus indicating that the amount of water necessary can be reduced materially through efficient use of a suitable wetting agent.

The amount of water used during top-cutting also may be reduced through application of wetting agents. More than 50 per cent greater reduction in dust density is possible with wetting agents in water than with water alone, or less than half as much liquid need be used for the same dust density.

The safety problem in coal mines arising from ex-

cessive coal dust, namely the hazard of widespread explosions and fires, ultimately will be solved by the measures indicated. These are:

(1) Use of water at and around the working faces.
(2) Use of water on the floor of main haulageways, with rock-dusting of all other accessible dry surfaces.
(3) Maintenance of active circulation of pure, fresh air currents throughout mines.
(4) Restriction or absolute prohibition of open flames (including smoking materials) or electric arcs.

Coal Dust Injures Health

A few years ago many investigators believed that coal dust not only was not harmful but that it exercised a favorable effect when inhaled with more dangerous dusts. More thorough investigation of the physical condition of workers in dusty industries is leading to a realization that although some dusts are more dangerous to health than others, all are more or less harmful under certain conditions of exposure. Although silica dust has been the principal focus of attention of those interested in dust diseases, other dusts may cause respiratory affections that may result in much suffering and economic loss. Such diseases as bronchitis, influenza, pneumonia, and tuberculosis are more prevalent among coal miners exposed to high concentrations of dust than among the general population engaged in occupations not having such dust exposure. Coal mining per se does not necessarily increase the incidence to respiratory disease, provided adequate precautions are taken.

Figures of mortality available for 4700 miners insured in the group department of the Metropolitan Life Insurance Co. show that in the last quarter of 1918 during the influenza epidemic the death rate was equivalent to 50 per 1000, while that for all occupied males aged fifteen years and over in the same three months was 22 per 1000, or less than half as high. In the age period 45 to 65 years the rate among bituminous-coal miners was about four times as high as among all occupied males in the same age group.

Influenza and pneumonia, as reported in the years under study, were responsible for 31 per cent of the mortality in the group of bituminous-coal miners at ages 16 to 70 in Indiana, Missouri, and Wyoming, compared with 19 per cent among both farmers and "all other males" at these ages in the same counties.

In the epidemic year 1920 the proportion of deaths from influenza and pneumonia was smaller than in 1918, but, as was found for the anthracite miners, the bituminous group showed a wider difference in the proportion of deaths from this cause compared with "all other males" than in 1918. The percentages in 1920 were 29 for the soft-coal miners and 16 for "all other males." In this epidemic the bituminous miners at ages 40 to 60 suffered heavy excess mortality from influenza-pneumonia, but the differential mortality was not quite so great as at ages 16 to 30.

Among hewers and getters of soft coal in England and Wales, the death rate from influenza and pneumonia, 1921-23, was about 12 per cent greater than among males of comparable social status. Thus, an abnormal mortality from influenza and pneumonia is consistently indicated among miners of coal, both anthracite and bituminous, in England as well as in the United States.

In a study of 774 bituminous-coal miners of the Southern Appalachian region, B. G. Clarke and C. E. Moffet found a tendency of bituminous-coal miners to develop presilicotic and silicotic lung changes after prolonged employment. At the mine where the study was made, 2 per cent of the workers showed presilicotic changes, and roentgenograms of the chests showed silicotic nodulation in 1 per cent, principally among undercutting machine operators and coal loaders. The shortest exposure period necessary to produce nodulation was observed in a rock driller who had worked at this occupation for eleven years.

In a study by the U. S. Public Health Service, in co-operation with the Utah State Board of Health, of bituminous-coal miners in Utah, sixteen cases of anthracosilicosis were found among 507 miners whose only occupational dust exposure had been in bituminous-coal mines. These cases were not advanced or seriously disabled. Only one case of moderately-advanced (second-stage) anthracosilicosis was found and no well-advanced (third-stage) case was observed. The typical picture of well-advanced anthracosilicosis found by the Public Health Service in a study of 2711 anthracite miners was not experienced among the Utah bituminous-coal

miners, but the changes disclosed in their films were similar to those in anthracite miners with early anthracosilicosis. The results of the investigations cited indicate the possibility of the occurrence of severe dust disease among bituminous-coal miners with long exposure to high concentrations of dust.

Methods of Control

Control of dust diseases in bituminous-coal mines requires the application of known, effective engineering, medical, and legal methods.

Engineering control—Use of water at and around the working faces; use of water on the floor of haulageways, particularly where sand, an important source of silica in mines, is used to prevent slipping of locomotives; maintenance of active circulation of pure, fresh air throughout; and other engineering methods devised for control of dust to minimize the explosion hazard also are effective in reducing the health hazard. The engineer, however, must bear in mind the objective in instituting his controls, for, although his methods for reducing dustiness may be similar the degree of control he will wish to exercise in particular sections of a mine or in the mine as a whole will depend upon whether he is primarily concerned with the danger to health or safety. Along main haulageways, for example, both hazards are of concern. Yet, should he approach the problem only from the safety standpoint and attempt to minimize the explosion hazard merely by extensive application of rock dust, he may be doing nothing to remove or minimize the health hazard, and in fact may actually increase the health hazard.

Control of the health hazard by engineering methods requires actual reduction of dust particles in the air in which men are exposed over long periods of time. From an explosion standpoint, a dust count of particles in the air running into the hundreds of millions of particles per cubic foot of air is not dangerous, but from the health standpoint the maximal permissible dust concentration should probably be in the neighborhood of five to fifty million, depending upon the amount of free silica present in the dusty air and the length of time which men are exposed in it. Moreover, another important distinction must be borne in mind: as mentioned before, it is the potential air-dustiness, namely the dust on roof, ribs, and floors which can be dislodged instantly and thrown into the air in response to sudden force, that constitutes a primary explosion hazard; whereas it is the dust actually in the air that constitutes the health hazard.

The aim of the engineer, in dealing with the health hazard, should be to work towards eliminating dust entirely from the air, and from a practical standpoint the engineer should carry out control measures which at least will effectively reduce the dust in the air to a concentration that will not cause disability during a working lifetime.

Medical control—The principal means of medical control is the physical examination of workers to determine their fitness for work requiring exposure to dust and the efficiency of control measures in effect. This presupposes not only pre-employment but also periodic postemployment examinations. Some states require the physical examination of employees, and one state, North Carolina, requires preemployment and periodic postemployment examinations of all employees exposed to the hazards of asbestos and silica dust. Another medical control measure is the education of all concerned regarding the danger of breathing large quantities of dust and the necessity that every individual (including workers) must do his personal share in trying to aid in reducing air-dustiness.

Legal control—Compensation for industrial diseases is one of the principal methods of legal control. At present 25 states and the District of Columbia have laws for the compensation of occupational diseases and in some silicosis is specifically mentioned in the law. In Pennsylvania the law applies to anthracosilicosis contracted in the anthracite mines. Formulation of codes of good practice, which attempt to establish allowable concentrations of dangerous dusts, is a comparatively recent trend in several states. In Wisconsin and New York the codes are legal and binding.

Although many medical and engineering problems remain unsolved, enough experimental and other data are available that, if properly applied, will enable those concerned to reduce to a negligible quantity the dust in bituminous-coal mines and thereby lessen the hazard to the life and health of the soft-coal miner.

The Post-War Highway Program

By CHARLES M. UPHAM
Engineer-Director
American Road Builders' Association

and DANIEL R. LAMSON
Research Engineer
American Road Builders' Association

• **Attention is being increasingly directed to the need and advantages of adequate post-war highway planning. Of especial interest, therefore, should be the observations of the American Road Builders' Association as outlined by Mr. Upham and Mr. Lamson.**

THE economic pitfalls that followed the first World War can be avoided after the second, if action is taken at once. Business collapse, widespread unemployment and governmental relief were the offspring of World War I. Insurance against the evils of another post-war depression is the objective of an economic study undertaken by the American Road Builders' Association. The post-war highway program that is urged by this study is designed to guarantee full employment and prosperity, with an orderly transition from wartime to peacetime pursuits at the close of the war.

Based on an analysis of the nation's entire economic structure, it recommends a program of essential construction to eliminate the necessity for useless governmental relief work. Study of economic trends in the past leave no doubt that the construction industry is the spark on which a prosperous national economy depends. The highway portion of the construction investment area more completely fulfills all requirements of a prosperous period than any other form of public construction. Augmenting the economic justification for a post-war highway program are the traffic demands which have advanced far beyond the capacity of the present highway system.

It is estimated that between 30,000,000 and 40,000,000 men will be released from the decelerating war industries and the United States military forces at the close of the war. In order to prevent depressed conditions, it is going to be necessary to provide these men with useful work. Planning now for a full-sized post-war program is the part that the highway industry and profession can play in winning the peace.

If a program is available so that these men can be put to work immediately, our economic problems will be held at a minimum. If there is no program in readiness to provide work for these men, a condition somewhat similar to that of the early thirties, but of much greater intensity, will prevail and the resulting depression will assume tremendous proportions. The government will not permit these men to remain idle. If there is no planned post-war program ready, a duplication of the CWA and WPA programs will be inevitable. Improvised work proved unsuccessful in the thirties, either for the relief of unemployment or as an economic stimulant. It can hardly be relied upon to improve a post-war situation involving the shifting of approximately 30,000,000 persons from wartime to peacetime activity.

Highway construction, while providing needed facilities, offers an excellent opportunity for the absorption of manpower. These objectives can be reached only by having available a shelf of projects, complete with plans, specifications and cost estimates, ready for contract at the end of the war. Many of the highway building agencies have formerly thought of highway programs in terms of a few millions of dollars. The post-war program must be in billions, if it is to fulfill its purpose. It must be of sufficient size to last over a period of years. A five or six-year program, regulated in size from year to year by economic demands, would result in the modernization of our present highway system and would eliminate the possibility of any industrial collapse.

Every state, county, city and regional area should have a planned program of highway construction. Reserve funds should be accumulated now to finance post-war projects or to participate with the federal government on a matching or loan-and-grant basis. The present lapse in highway construction offers an excellent opportunity to plan a program that will result in a modern network of highways. Co-ordinated action by states, counties and cities has long been desired and if, at the end of the war, a plan which will remove our traffic bottlenecks is in readi-

ness, funds which might otherwise be wastefully spent on relief work will be spent on the much-needed improvement of our highway system.

It is possible that private construction, which should normally constitute the greater percentage of the post-war construction volume, will be slow in starting. It is, therefore, imperative that the highway construction program should be ready to fill this lag or any subsequent let-down in private construction which may occur. There must be a shelf of highway projects of sufficient size to insure an annual $3,000,000,000 program for at least five years. This $3,000,000,000 program, a figure somewhat higher than the 1929 construction program, would include federal, state, county and municipal construction.

It has been found that in recent periods of our greatest prosperity, construction investment varied from 12 to 15 per cent of our national income. To reproduce these prosperous times, therefore, would mean that at least 12 per cent of our national income should be invested in construction. Full employment at present wage schedules is essential to prosperity. Analysis of the factors involved shows that this condition is achieved when the national income is from $100,000,000,000 to $105,000,000,000. This means that prosperity requires a total construction program of $12,500,000,000 to $15,000,000,000, including private, corporate and federal construction.

The private program for a period of years after the war has been estimated at $10,000,000,000 a year. Supplementing this, public expenditures of $5,000,000,000 could be spent on useful projects, to include $3,000,000,000 on highways and $2,000,000,000 on other public works. In this last category, airports and flight strips should take up a substantial amount of the work. Necessitating as it does the use of the same materials and equipment as highway construction and the same type of engineering and contracting, airport construction actually becomes part of the highway program.

Department of Labor employment studies of 10 different classifications of public works projects show that streets and roads furnish the most on-site and off-site employment per dollar invested. It was also found that highway projects could be more quickly started and finished than any of the other classifications. Large highway construction projects require no more, if as much, time to reach the various stages of completion than the smaller projects. It was also found that the maximum labor force occurred sooner in highway and street construction than in any other classification. Construction programs carried on during the depression years by contract and day-labor methods also proved the advantages of contract construction. To receive the full economic benefits of a construction program, the contract system must be used.

Public Roads Administration studies show that every dollar spent on highway construction eventually goes to labor and that every highway dollar expands into three dollars in business value. Highways exceed all other public construction in the creation of secondary employment and encouragement for investment of private capital. When money is put into a highway, not only are men put to work on its construction but many new employment activities are created. Filling stations, garages, hotels, bus companies, roadside stores are examples of the many private enterprises that result from highway construction.

Statewide fact-finding surveys have ben made as a part of the preparation of a master plan for a national system of highways. They indicate that the cost of the construction, reconstruction and modernization program needed for the entire nation would total many billions of dollars and would necessarily have to be spent over a period of years. These funds must be spent in a co-ordinated plan which will result in meeting the demands of traffic in all areas.

In urban areas the program would include the construction of belt-line limited-access highways to take traffic around these areas and arterial highways into and through them. This type of construction necessitates the building of overpasses, underpasses and multi-lane highways. The construction of parking facilities in urban areas should also be an important part of the post-war program. Much of the secondary highway system was designed for small volume and low-speed traffic which has caused excessive maintenance costs. The program would require the raising of low-type surfacing to higher types, as well as much relocating and widening. The construction of airports and flight strips, auxiliary landing areas for aircraft, is sure to be an important part of the construction program.

It is essential that states, counties and cities prepare their plans without delay in order that the program may be ready to swing into action as soon as the war is won. The highway profession and industry is charged with this responsibility not only from an economic standpoint but also to give assurance now to war workers and military forces that there will be no lack of worthwhile employment after the war.

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Minneapolis, Minn.
Rock Crushing, Conveying and Transmission Machinery

E. I. du Pont de Nemours & Co., Inc.
Wilmington, Del.
Explosives and Blasting Accessories

Dymonhard Corporation of America
250 West 57th St., New York City
Hard Facing Welding Rods

Easton Car and Construction Co.
Easton, Pa.
Quarry Cars, Truck Bodies and Trailers
Electric Heaters for Tar, Asphalt or Bitumen

Ensign-Bickford Co.
Simsbury, Conn.
Cordeau-Bickford Detonating Fuse and Safety Fuse

MANUFACTURERS' DIVISION of the NATIONAL CRUSHED STONE ASSOCIATION

Frog, Switch & Mfg. Co.
Carlisle, Pa.
Manganese Steel Department—Manufacturers of "Indian Brand" Manganese Steel Castings for Frogs, Switches and Crossings, Jaw and Gyratory Crushers, Cement Mill, Mining Machinery, etc., Steam Shovel Parts

General Electric Co.
1 River Road, Schenectady N. Y.
Electric Motors

Goodyear Tire & Rubber Co.
Akron, Ohio
Belting (Conveyor, Elevator, Transmission), Hose (Air, Water, Steam, Suction, Miscellaneous), Chute Lining (Rubber)

Gruendler Crusher and Pulverizer Co.
2915 N. Market St., St. Louis, Mo.
Rock and Gravel Crushing and Screening Plants, Jaw Crushers, Roll Crushers, Hammer Mills, Lime Pulverizers

Hayward Co.
50 Church Street, New York City
Orange Peel Buckets, Clam Shell Buckets, Drag Line Buckets, Electric Motor Buckets, Automatic Take-up Reels

Hendrick Mfg. Co.
Carbondale, Pa.
Perforated Metal Screens, Perforated Plates for Vibrating, Shaking and Revolving Screens; Elevator Buckets; Hendrick Vibrating Screens

Hercules Powder Co.
Wilmington, Del.
Explosives and Blasting Supplies

Illinois Powder Mfg. Co.
124 N. 4th St., St. Louis, Mo.
Gold Medal Explosives

Iowa Manufacturing Co.
Cedar Rapids, Iowa
Rock and Gravel Crushing, Screening, Conveying and Washing Plants, Hot and Cold Mix Asphalt Plants, Stabilizer Plants, KUBIT Impact Breakers, Screens, Elevators, Conveyors, Portable and Stationary Equipment.

Kennedy-Van Saun Mfg. and Eng. Corp.
2 Park Ave., New York City
Material Handling Machinery—Crushers, Pulverizers, Vibrating Screens

Kensington Steel Co.
505 Kensington Ave., Chicago, Ill.
Manganese Steel Castings, Dipper Teeth, Crawler Treads, Jaw Plates, Concaves and Hammers

Keystone Driller Co.
Beaver Falls, Pa.
Drills, Power Shovels

The King Powder Co., Inc.
Cincinnati, Ohio
Detonite, Dynamites, and Blasting Supplies

Koehring Co.
3026 W. Concordia Ave., Milwaukee, Wis.
Mixers, Pavers, Shovels, Cranes, Draglines, Dumptors, Traildumps, Mud-Jacks

Kotal Company
52 Vanderbilt Ave., New York City
KOTAL, the Waterproofing Agent for Aggregates that Improves Hot Mixes, Cold Mixes, Traveling Plant Mixes and Road Mixes of Bitumen

Lima Locomotive Works, Inc.
Shovel and Crane Division
1108 Lima Trust Bldg., Lima, Ohio
Power Shovels, Draglines and Cranes

Link-Belt Co.
300 West Pershing Road, Chicago, Ill.
Complete Stone Preparation Plants. Conveyors, Elevators, Screens, Washing Equipment, Speed-o-Matic Shovels—Cranes—Draglines and Power Transmission Equipment

Ludlow-Saylor Wire Co.
Newstead Ave. & Wabash R. R., St. Louis, Mo.
Woven Wire Screens and Wire Cloth of Super-Loy, Manga-Loy and all commercial alloys and metals

Mack Manufacturing Corp.
34st St. & 48th Ave., Long Island City, N. Y.
Trucks, Truck-Tractors of All Types and Capacity, Gasoline or Diesel Power Optional

MANUFACTURERS' DIVISION of the NATIONAL CRUSHED STONE ASSOCIATION

Marion Steam Shovel Co.
Marion, Ohio
A Complete Line of Power Shovels, Draglines and Cranes

McLanahan & Stone Corp.
Hollidaysburg, Pa.

The National Supply Co., Superior Engine Division
1401 Sheridan Ave., Springfield, Ohio
Diesel Engine Equipment

Nordberg Mfg. Co.
Milwaukee, Wis.
Cone Crushers, Vibrating Screens, Diesel Engines, Steam Engines, Compressors, Mine Hoists, Underground Shovels, Track Maintenance Tools

Northern Blower Co.
65th St. South of Denison, Cleveland, Ohio
Dust Collecting Systems, Fans—Exhaust and Blowers

Northwest Engineering Co.
28 E. Jackson Blvd., Chicago, Ill.
Shovels, Cranes, Draglines, Pullshovels

Parsons Engineering Corp.
3599 E. 82d St., Cleveland, Ohio
Dust Collecting Systems: Fans, Hoods and Blow Piping

Pioneer Engineering Works, Inc.
1515 Central Avenue, Minneapolis, Minn.
Jaw and Roll Crushers, Vibrating and Revolving Screens, Scrubbers, Belt Conveyors, Traveling Grizzley Feeder

Pit and Quarry Publications
538 South Clark St., Chicago, Ill.
Pit and Quarry, Pit and Quarry Handbook, Pit and Quarry Directory, Concrete Manufacturer, Concrete Industries Yearbook

Robins Conveying Belt Co.
Passaic, N. J.
Belt Conveyors, Bucket Elevators, Gyrex and Vibrex Screens, Feeders, Design and Construction of Complete Plants

Rock Products
309 West Jackson Blvd., Chicago, Ill.

Ross Screen and Feeder Co.
19 Rector St., New York City
Ross Patent Chain Feeders for Feed Control of All Sizes Rock, Ores, Gravel, etc.

Screen Equipment Co.
9 Lafayette Ave., Buffalo, N. Y.
SECO Vibrating Screens

Simplicity Engineering Co.
Durand, Mich.
Simplicity Gyrating Screen, Simplicity D'centegrator, Simplicity D'watering Wheel

Smith Engineering Works
E. Capitol Drive at N. Holton Ave.,
Milwaukee, Wis.
Gyratory, Gyrasphere, Jaw and Roll Crushers, Vibrating and Rotary Screens, Gravel Washing and Sand Settling Equipment, Elevators and Conveyors, Feeders, Bin Gates, and Portable Crushing and Screening Plants

Stedman's Foundry & Machine Works
Aurora, Indiana
Stedman Impact-Type Selective Reduction Crushers

Taylor-Wharton Iron & Steel Co.
High Bridge, N. J.
Manganese and other Special Alloy Steel Castings

The Texas Co.
135 E. 42nd St., New York City
Asphalts, Lubricating and Fuel Oils

The Thew Shovel Co.
Lorain, Ohio
Power Shovels, Cranes, Crawler Cranes, Locomotive Cranes, Draglines. Diesel Electric, Gasoline. 3/8 to 2-1/2 cu. yd. capacities

The Traylor Engineering & Mfg. Co.
Allentown, Pa.
Stone Crushing, Gravel, Lime and Cement Machinery

Trojan Powder Co.
17 N. 7th St., Allentown, Pa.
Explosives and Blasting Supplies

The W. S. Tyler Co.
3615 Superior Ave., N. E., Cleveland, Ohio
Wire Screens, Screening Machinery, Scrubbers, Testing Sieves and Dryers

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